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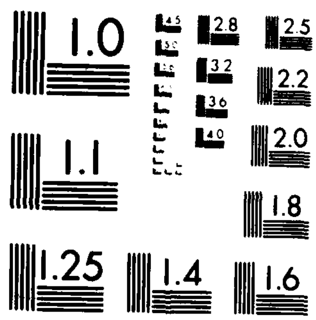
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FOREIGN TECHNOLOGY DIVISION

THYRISTOR CONVERTER FOR CAPACITIVE LASER ACCUMULATORS

by

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EDITED TRANSLATION

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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THYRISTOR CONVERTER FOR CAPACITIVE LASER ACCUMULATORS

G. L. Benediktov

Charging of a capacitor bank with a high capacitance, considering economic, weight and size indices, represents a complex problem. Different aspects of this problem have been treated in the literature both for stationary installations and for mobile devices [1-3]. The layouts used in the majority of cases, ensuring a constancy of discharge current, possess high efficiencies and have small dimensions. if power supply is realized from an ac power system or from a power--consuming storage battery. In a whole number of cases the average power consumed by a capacitive accumulator of gas-discharge lamps of optical quantum generators (OKG) [lasers] is comparable with the power of the primary source of energy. With a constancy of charging current the fluctuations of power consumed from the source will be considerable - from zero to a twofold value of the magnitude of average power. In this case it is necessary to take special measures for increasing the flywheel moments of the electric generators for reducing the dynamic shocks on the shaft of the primary motor.

In the case of a low frequency of discharges of the pulse accumulator the curve of active power consumed from the generator will have a considerable low-frequency component. For reducing it in the curve of the moment acting on the primary motor it is necessary to increase to a considerable degree the moments of inertia and the weight of the rotating parts of the electric generator, which increases the weight and the dimensions of the entire system. If the active power is maintained on a constant level in the process of charging,

the requirements for the source of power are lowered considerably and on the whole the system will have lesser weights and dimensions.

In this work it is proposed to solve this problem with the help of thyristors. The preliminary selection of the layout can be realized from the following considerations:

- the layout should obtain power from a three-phase source, ensuring the continuous supply of energy to it;
- it is expedient to carry out the transformation of voltage on a higher frequency;
- a single-phase layout of transformation and rectification is preferable, since it has a lesser number of elements.

Thus with a calculation of these requirements the layout should consist of a converter of three-phase voltage into one-phase voltage of increased frequency, a single-phase transformer, a single-phase bridge rectifier, and a current-limiting reactor. A layout answering these requirements is shown in Figure 1. The main element of the layout is the converter of three-phase voltage into a sequence of sign-variable pulses. The pulses of charging current are formed due to the capacitance of accumulator C, inductance of transformer L_T and inductance L of the charging reactor Dr_1 on the side of direct current with the inclusion of each of the six thyristors. The pulse of charging current, without taking into account the losses in the trans and in the charging circuit, is determined by the operator expression

$$i(p) = \frac{\sqrt{2}\,nU}{(L_T+L)}\,\frac{p^2\sin\beta + p\,\omega\cos\beta}{(p^2+\omega^2)(p^2+\omega_0^2)} - \frac{U_0}{(L_T+L)(p^2+\omega_0^2)}, \qquad (1)$$

where U - linear voltage of the three-phase network of alternating current; n - coefficient of transformation of the transformer; ω - frequency of the power-supply network; $\omega_0 = 1/\sqrt{(L_T+L)C}$ - frequency of natural fluctuations of the charging circuit; U_0 - voltage on the accumulator at the moment of turning on the thyristor; β - angle, determining the phase of the power-supply voltage at the moment of turning on of the thyristor, it is calculated from the moment of turning on of the thyristor to the specific moment of change of sign of the linear voltage.

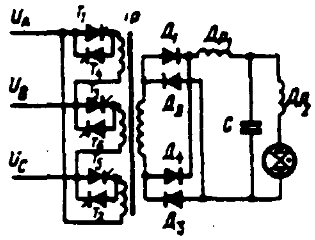

Figure 1. Schematic of a thyristor converter for capacitive accumulators.

It can be shown that for $\omega_0 \leq \omega$ the duration of pulses of current in the case of a change of voltage on the accumulator from zero to the amplitude of the power-supply voltage will be less than one-sixth of the period of power-supply voltage. This ensures the independent operation of the thyristors and makes it possible to use a single-phase transformer. A constancy of the gain of energy during the time of each pulse in the process of charging the capacitor can be ensured by changing the angle β . The magnitude of the increase of energy of the accumulator is connected with the magnitude of the increase of voltage during the time of each pulse by the correlation

$$\Delta W = CU_0 \Delta U + 0{,}5C(\Delta U)^2, \qquad (2)$$

where C - capacitance of the accumulator; ΔU - increase of voltage on the capacitor during the time of the pulse.

The magnitude of increase of voltage on the capacitor during the time of each pulse can be determined from (1):

$$\Delta U(p) = \frac{i(p)}{pC} = \sqrt{2}\, nU \omega_0^2 \frac{p \sin\beta + \omega\cos\beta}{(p^2+\omega^2)(p^2+\omega_0^2)} - \frac{\omega_0^2 U_0}{p(p^2+\omega_0^2)}. \qquad (3)$$

Figure 2 shows the curves, constructed in accordance with formulas (2) and (3), of change of increase of energy on a capacitor for a single charging pulse depending on the initial conditions. The base value of energy is the energy of the capacitor, charged up to the amplitude of linear voltage, reduced to the side of the accumulator.

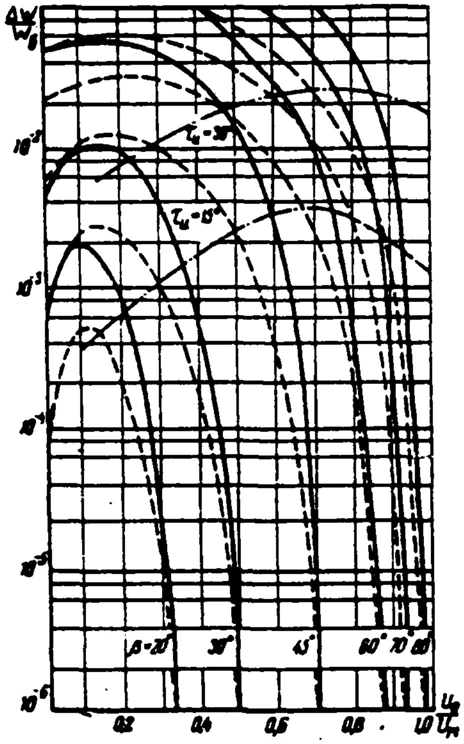

Figure 2. Dependence of the increase of energy on the accumulator on the initial voltage on the capacitor with different initial phases of power voltage:

——— $-\ \omega = \omega_0$; ----- $-\ \omega = 2\omega_0$.

The initial voltage on the capacitor refers to the amplitude of linear voltage, reduced to the side of the accumulator. The curves are constructed with constant values of the angle β=20°, 30°, 45°, 60°, 70°, 80°. For each angle of inclusion the magnitude of increase of energy is determined with $\omega_0 = \omega$ and ω_0=0.5ω. On the graph the curves of pulses of current of equal duration are noted. These curves in the case of $\omega_0 = \omega$ and ω_0=0.5ω have approximately the same form, determined by the coincidence of the forms of the pulses of current of charging with uniform increases of energy and equal initial voltages on the capacitor. The curves in Figure 2 make it possible to determine the necessary angles of control of β depending on the voltage on the capacitor at the assigned values of increase of energy in the capacitor for each pulse of charging current, i.e., with a constant value of active power. The graphic dependence of angle β on voltage

on the accumulator makes it possible to construct a system of control of the thyristors, ensuring a constancy of consumed power.

In the case of high voltages on the accumulator a galvanic connection between the accumulator and the system of control is not desirable. In this case it is possible to use a current measuring element. The functional dependence of the angle β on the charging current can be obtained from the dependence of angle β on voltage on the accumulator and the dependence, connecting the current and voltage on the accumulator. The latter can be determined by using difference equations. In the case of a constancy of energy supplied to the capacitive accumulator for each pulse of charging current, the law of change of voltage on the capacitor in the beginning of each charging pulse is written

$$U_{0h} = \sqrt{\frac{2Wh}{CN}}. \tag{4}$$

where W - energy in the accumulator at the end of the process of charging; h - number of pulse of charging current; N - total number of pulses of current. Then the increase of the charge on the accumulator will be

$$\Delta Q_h = C\left(U_{0(h+1)} - U_{0h}\right) = \sqrt{\frac{2WC}{N}} \frac{1}{\sqrt{h+1}+\sqrt{h}}. \tag{5}$$

Taking (4) and (6) into account, we determine the magnitude of average current for an interval, related to the magnitude of average current for the entire cycle of the charging:

$$\frac{I_{cph}}{I_{cp}} = \frac{\sqrt{N}}{\sqrt{h+1}+\sqrt{h}}. \tag{6}$$

Expressions (4) and (6) make it possible to determine the dependence of the angle of control β for discrete points of the charging process.

Calculation of the modes of charging of the accumulator in the case of assigned values of voltage U_N on the accumulator at the end of charging, energy of the charge W and the duration of the charging process T can be made, having assigned the magnitude of amplitude of ac voltage U_M. The total number of cycles N is determined by the

duration T of the charging process and the frequency of the network f: $N=6fT+1.5$. The necessary magnitude of increase of energy will be

$$\frac{\Delta W}{W_6} = \frac{U_N^2}{NU_M^2}.$$

From the graph in Figure 2 for the given value $\frac{\Delta W}{W_6}$ the possible value of $\frac{\omega}{\omega_0}$ and the dependence of angle β on voltage on the capacitor are found. Using expressions (4) and (6), it is possible to determine the dependence of angle β on the magnitude of average current for a pulse. As an example of the determination of the dependence of angle β on the relative current $\frac{I_{cp\phi}}{I_{cp}}$ Figure 3 shows the dependence when

$$\frac{U_M}{U_N} = 1.11, \quad \frac{\Delta W}{W_6} = 10^{-3},$$
$$\omega = \omega_0, \quad N = 800.$$

Figure 3 also gives the dependence of the increase of control voltage on the average current (in standardized units), determined from the expression

$$\frac{\Delta U_y}{\Delta U_{yM}} = \frac{90^\circ - \beta}{90^\circ},$$

where ΔU_y - increase of control voltage, necessary for changing the phase of the control pulse by the angle $90^\circ - \beta$; ΔU_{yM} - maximum change of control voltage, ensuring a change of phase of the control pulse by 90°.

A similar dependence can be obtained easily, using a saturating current transformer, a rectifier with filter and a voltage divider with a variable coefficient of division. By comparing this dependence with the saw-tooth voltage, synchronous with the network voltage, it is possible to obtain the necessary law of change of angle β in time depending on the magnitude of average current (time of averaging - 1/6 a period of power-supply voltage). The thyristor control system should consist of a six-phase generator of saw-tooth voltage, six comparison circuits, and six pulse amplifiers.

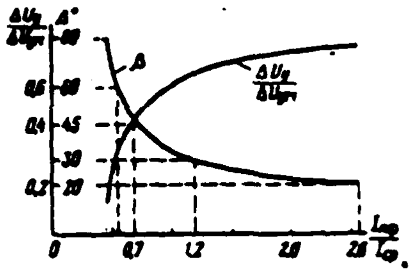

Figure 3. Dependence of the angle of inclusion of thyristors β and control voltage $\frac{\Delta U_y}{\Delta U_{yM}}$ on the magnitude of the average current for a pulse.

The thyristor converter, made in this arrangement, was investigated in modes with a frequency from fractions of a Hertz to two Hertz with power supply from a three-phase 50 Hz network. The law of a change of voltage in the case of capacitance charging was controlled with the help of an I-5M electronic indicator. As is evident from the table, the actual law of change of voltage for capacitance differed from the law, determined by expression (4), by a magnitude less than the calculated error of the system of measurement (5%).

Table

Опытные данные (1)		(2) Расчетные данные	
U, в (V)	t, сек (s)	U_{0h}, в (V)	h
240	0,267	246	80
350	0,532	350	160
500	1,60	493	320
610	1,60	605	480
700	2,15	696	640
780	2,67	780	800

Key: (1) Test data; (2) Calculated data.

CONCLUSIONS

1. Theoretical and experimental investigations showed the possibility of construction of a thyristor converter for power supply of capacitive accumulators of gas-discharge lamps for a laser with provision for constancy of power consumed from the power source.

2. The curves given for the law of change of energy depending on voltage on the accumulator capacitance and the expressions for current and voltage in the charging circuit make it possible to make an engineer calculation of the circuit of the thyristor converter.

3. The proposed method of calculating the process of charging of a capacitive accumulator can be used for the calculation of a circuit, providing other laws of change of power in time which differ from the law P=const.

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